Uncertainties and Interdisciplinary Transfers Through the End-To-End System (UNITES)

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Award Number: N0001401WR20335

LONG-TERM GOAL

The overall goals of this research are:

1. To define and characterize the variabilities and uncertainties in the components and linkages of the general physical-geo-acoustical system relevant to the support of naval operations.
2. To transfer quantitatively the spatial-temporal environmental variabilities and uncertainties through the interdisciplinary system, including coupled interactions, in order to determine uncertainty measures, sensitivities and feedback needed to improve operational predictions and parameters.

OBJECTIVES

This effort is part of a multi-institutional team effort to capture uncertainty in the common tactical picture. The team's name is UNITES, which stands for UNcertainties and Interdisciplinary Transfers through the End-to-End System. Led by Abbot, OASIS, Inc., and Robinson, Harvard University (HU), the UNITES team, with expertise spanning the ocean environment, underwater acoustics and tactical sonar systems, consists of a total of twelve principal investigators from nine different organizations including the Naval Postgraduate School (NPS), Woods Hole Oceanographic Institution (WHOI) and University of North Carolina (UNC).

The NPS component in the UNITES team's paradigm to solve the interdisciplinary, end-to-end problem has two objectives:

1. To characterize acoustic prediction uncertainties, including their connections to the uncertainties in the ocean and geo-acoustic parameter estimates.
2. To forecast and improve acoustic baselines and their uncertainties in a data-assimilation framework involving coupled ocean and acoustic state variables.

APPROACH

The research will focus on a shelfbreak environment, encompassing the outer continental shelf and the continental slope, where the physical oceanography, specifically the shelfbreak front, internal tides and internal solitary waves, play a significant role in introducing acoustic prediction uncertainty at multiple time and space scales. The acoustic prediction uncertainty is further complicated by the variable

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2001		**00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Uncertainties and Interdisciplinary Transfers Through the End-To-End System (UNITES)**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Oceanography,,Naval Postgraduate School,,Monterey,,CA, 93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

bathymetry and inhomogeneous sediment properties as the water-column variability shifts the insonified bottom locations from time to time.

The approach will entail both data analysis and modeling utilizing the coupled environmental and acoustic data sets from both Shelfbreak PRIMER and the Asian Sea International Acoustics Experiment (ASIAEX). The Shelfbreak PRIMER data set, obtained in the Middle Atlantic Bight (MAB) shelfbreak region during the summer of 1996, will be utilized in the first two years, 2001 and 2002, to gain fundamental insights into uncertainty transfer and characteristics, and to test and refine methodologies and the associated computer codes for linking and integrating ocean, acoustic and sonar models and data. The ASIAEX data was collected in May of 2001 in the South China Seas (SCS) with enhanced resolution in the environmental (both ocean and geo) parameters as well as the acoustic wavefields. The ASIAEX acoustic measurements have much improved coverage in frequency, source depth and range, propagation path orientation, and the spatial properties of the sound field. The processed data will become available in 2003. In the final two years of this effort the techniques developed in the previous years will be applied to the ASIAEX data to capture and characterize acoustic prediction uncertainty in the SCS shelfbreak region that are geographically and dynamically different from the Shelfbreak PRIMER site. Comparison between the acoustic prediction uncertainty characteristics for the MAB and SCS shelfbreaks will be conducted to resolve differences, similarities and dependency. This understanding is crucial to the design of sonar tactics such as optimum selection and placement of sonar systems for different types of shelfbreak regimes.

In acoustic prediction uncertainty characterization and linkage, the NPS work will be closely tied to that of OASIS, UNC, WHOI and HU. Depending on the space and time scales, probability density functions, PDF’s, of uncertainties in the acoustic variables, TL, amplitude, phase, time, wavenumber, etc., will be either estimated from observed environmental and acoustic data or based on Monte Carlo simulation using the Harvard Ocean Prediction System (HOPS) ocean realizations and UNC’s geo-acoustical parameter realizations. Climatological data or a single profile and first-order bottom model will be used to define the acoustic baselines from which uncertainties are realized. The broadband, coupled normal-mode model of Chiu et al. (1996) will be used to perform all sound propagation calculations. The estimated uncertainty statistics will be provided to OASIS, who will transfer the acoustic uncertainties to sonar performance uncertainties for several selected systems. Additionally, these sophisticated data products and model calculations will be used to crosscheck the first-order, but more physically insightful, analytical models, to be developed by WHOI, for acoustic uncertainty statistics and predictability. These simplified moment solutions by WHOI, in turn, will be used to facilitate the development of simple, robust rules-of-thumb.

For acoustic baseline and uncertainty forecast, a coupled ocean and acoustic methodology to assimilate oceanographic and acoustic data into HOPS will be developed. The basic approach is that of error subspace data assimilation of Lermusiaux (1999) and Lermusiaux and Robinson (1999). The novelty here is that the acoustic variables are treated as additional state variables in the ocean forecast model that is tightly coupled to the acoustic propagation model. The algorithm, therefore, simultaneously tracks, i.e., forecasts, the dominant error/uncertainty structures in both the ocean and acoustic variables, in addition to improving the baselines.

WORK COMPLETED

In close collaboration with HU and based on Error Subspace Statistical Estimation (ESSE), a methodology for the modeling and prediction of coupled ocean physics and acoustic uncertainties was developed and tested with the Shelfbreak PRIMER data. The test was a case study of the linkage between ocean mesoscale uncertainties and acoustic wavefield uncertainties in a slope-to-shelf transmission across the MAB shelfbreak front.

RESULTS

Based on observed oceanographic data during Shelfbreak PRIMER, HOPS was initialized with perturbed physical oceanographic fields that are in statistical accord with a realistic error subspace and then integrated to produce 80 realizations of a regional forecast of the sound-speed field. The different forecast realizations of the sound speed were then fed into a coupled-mode sound propagation model to produce realizations of the transmission loss (TL) prediction for a low-frequency transmission from the slope, across the shelfbreak, onto the shelf. Specifically, the transmission frequency was 400 Hz and the sound source was located near the bottom at the 300-m isobath on the slope. Six of the 80 different realizations of the TL prediction are shown in Fig. 1. They show that the structure in the spatial distribution of the acoustic energy is quite different from one realization to another, even in the shelf region where the ocean variance is minimal. The TL structure on the shelf is largely determined by what happens to the acoustic energy prior to entering the shelf. With the large sound-speed variances over the slope, the initial distribution of the acoustic energy over the set of acoustic normal modes (i.e., modal excitation) near the source range, as well as the redistribution of modal energy along the slope due to mode coupling, are different for the different ocean realizations. This results in different TL structures on the shelf (Fig. 1).

To summarize the forecast error statistics (uncertainty) for the TL prediction and its relation to the uncertainty in the ocean forecast, we show the error standard deviations of the sound-speed forecast in Fig. 2, the error standard deviations of the TL prediction in Fig. 3, and the corresponding histograms (error PDF estimates) for the sound speed and TL variables at two different locations, shelfbreak and shelf, in Fig. 8, respectively (all computed from 80 realizations). The error standard deviations of sound speed (Fig. 2) calculated from the ocean realizations show that large uncertainties are confined in the top layers (from 0 to 50m depth, with a maximum around 30m depth) over the slope region at the frontal zone. Over the shelf, the HOPS model predicts only relatively small error variances at the mesoscale. Accordingly, the error variance in the TL prediction (Fig. 3) is small near the source below the top layers, but as the acoustic energy reaches these top layers where large sound speed error variances are confined, the error variances in TL increase. Note that the uncertainty in the TL does not grow in range over the shelf where sound speed uncertainties are relatively small. The complexity and inhomogeneity of the predicted error statistics in this slope-to-shelf transmission in the MAB are further revealed in the PDF estimates shown in Fig. 4. In particular, note the transformation of the PDF shape as uncertainties are transferred from the ocean (sound speed) estimate to the acoustic (TL) estimate. Because the sound pressure field, from which TL is computed, is composed of multiple acoustic modes, an in-depth understanding of the linkage between the error statistics of TL and sound speed behooves a careful analysis on the behavior of the errors in the amplitude and phase of each acoustic mode. This modal error analysis is being carried out at present.

IMPACT/APPLICATIONS

The characterization of the uncertainties in the ocean and acoustic estimates and the understanding of the linkage of these uncertainties are crucial to the design of sonar tactics such as optimum selection and placement of sonar systems in different environmental regimes.

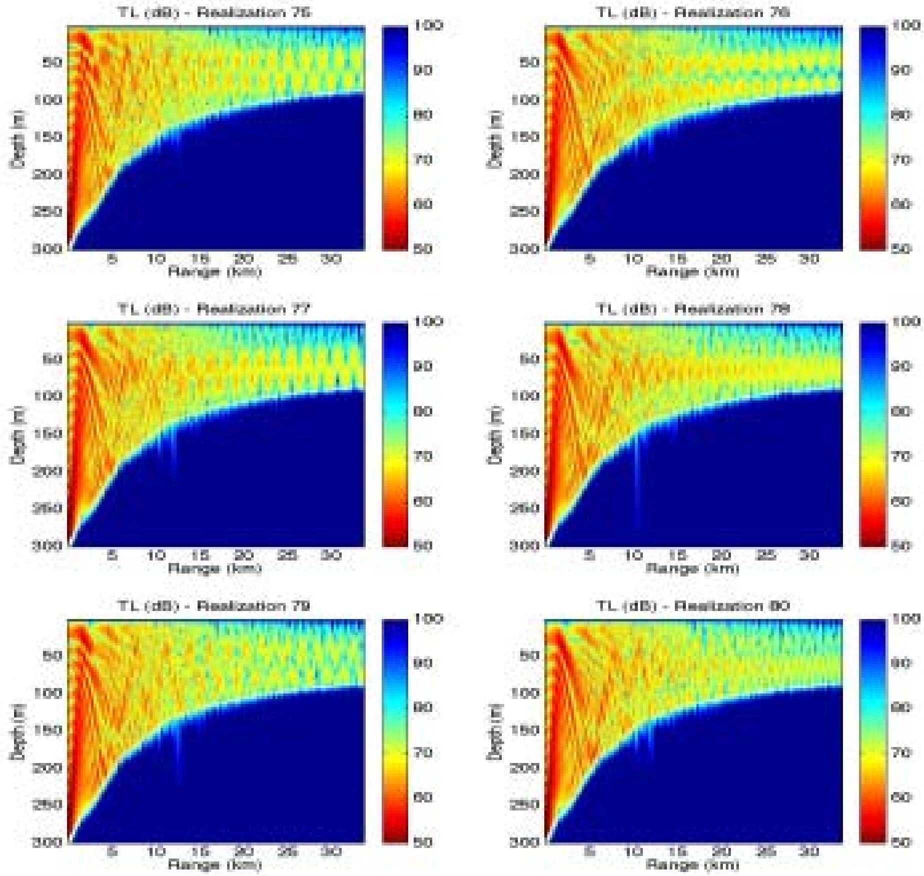

Figure 1. Six different realizations of the TL prediction. The prediction is for a 400-Hz transmission from the slope, across the shelfbreak, and onto the shelf, in the Middle Atlantic Bight, southeast of New England.

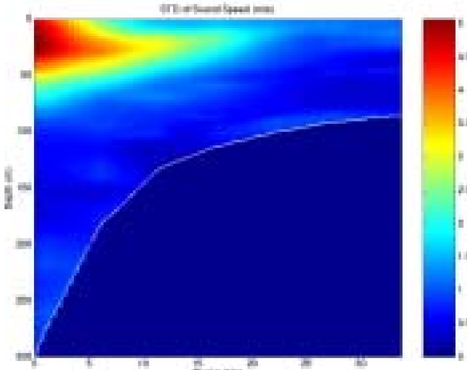

Figure 2. Error standard deviation estimate of sound-speed forecast.

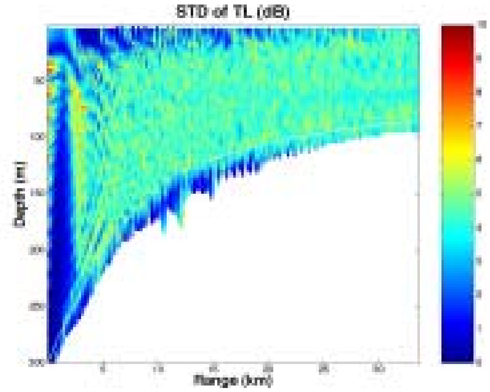

Figure 3. Error Standard deviation estimate of TL prediction.

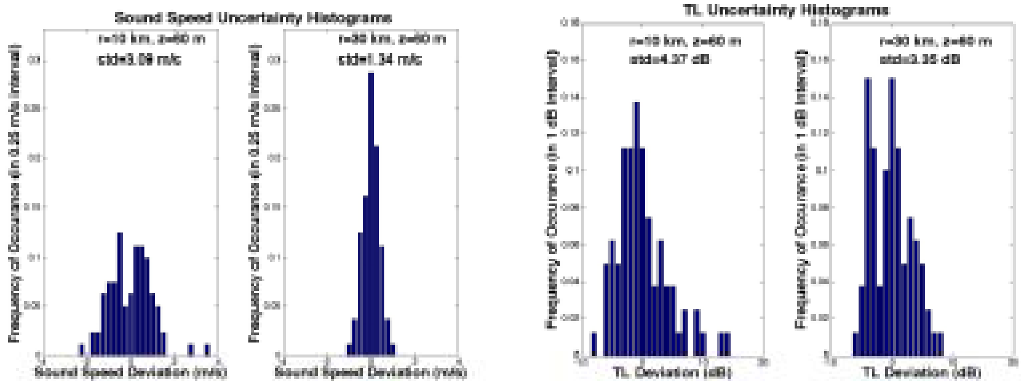

Figure 4. The histograms (PDF estimates) of the sound speed and TL uncertainties at two different locations (shelfbreak and shelf).

TRANSITIONS

This work will estimate the acoustic wavefield uncertainty statistics. These statistics will be provided to OASIS, Inc., another member of the UNITES team, to evaluate the performance of three fleet sonar systems in a probabilistic framework.

RELATED PROJECT

This project utilizes the experimental data sets obtained in Shelfbreak PRIMER and ASIAEX.

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PUBLICATION

Lermusiaux, P. F. J., C.-S. Chiu and A. R. Robinson, "Modeling Uncertainties in the Prediction of the Acoustic Wavefield in a Shelfbeak Environment," Proceedings of the 5th International Conference in Theoretical and Computational Acoustics, Beijing, China, 2001, in press.